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Atomic & Optical Theory

Modeling Artificial Guide Stars

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For centuries, astronomers have been frustrated by the fact that pristine light from the heavens is corrupted in the last millisecond of its journey to their telescopes, spoiling the nearly perfect image resolution that would be possible were it not for the Earth's atmosphere. The spectacular success of the Hubble Space Telescope (HST) is due in large part to the fact that, at an altitude of 615 km, it is free from the image-degrading effects of atmospheric turbulence.

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Developments in computers, imaging devices, and other areas have made it possible, in principle, for ground-based telescopes to produce images comparable in quality to the HST (see figure). The technology requires light from an “artificial guide star;” the most attractive one at present being created by beaming a laser up to the mesosphere. The laser light is absorbed by a layer of sodium atoms at 90 km, which then radiate yellow photons serving as the guide star. (The “sodium layer” in the mesosphere is about 10-km thick and is believed to be a consequence of meteoric ablation.) Adaptive optical techniques use measured atmospheric distortions of the light from the guide star to correct for the deleterious effects of the atmosphere on the image of an astronomical object of interest.

We have developed a theoretical basis and a set of computer codes that allow us to predict guide-star brightness under a variety of laser excitation schemes. In the past two years we have modeled and successfully predicted photon fluxes or other quantities measured

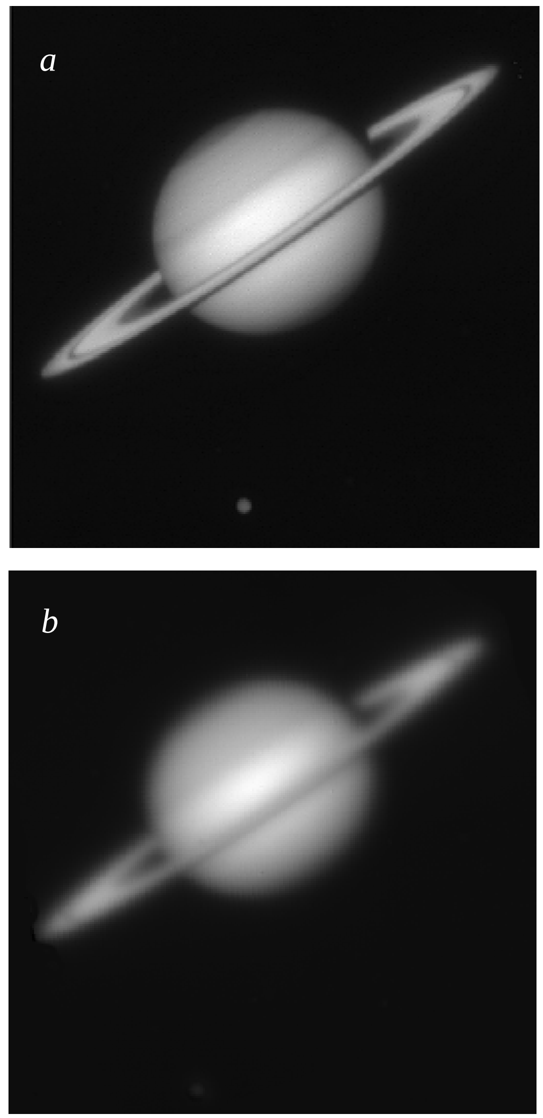

Figure: Images of Saturn and one of its moons (Titan), with (a) and without (b) adaptive optics using an artificial guide star, obtained with the 1.5-m telescope at the Starfire Optical Range. (Courtesy of Dr. Robert Q. Fugate.)

in experiments by six different groups. At the present time there are about a dozen observatories working on artificial guide-star systems to improve the imaging quality of large-aperture telescopes. Our work has been performed in close collaboration with colleagues at the Starfire Optical Range (Air Force Research Laboratory, Kirtland AFB). This group, led by Dr. Robert Fugate, has been at the forefront of research on adaptive optics and laser guide stars. Based partly on conclusions drawn from our work, the Starfire group is planning to develop a continuous-wave (cw) laser system for creating a mesospheric sodium guide star.

The analysis of cw guide stars requires consideration of several effects that are relatively slow and could therefore be ignored in our earlier analyses of short-pulsed excitation. These include atomic collisions that can change the spin states of the sodium atoms, the effect of the Earth's magnetic field in reorienting the atomic spins, the Earth's rotation, the recoil of the sodium atoms upon the emission or absorption of light, and diffusion of atoms out of the region illuminated by the laser.

The first successful implementation of the sodium guide star for astronomical image restoration was realized in 1997. It is conceivable that other types of artificial guide stars might be advantageous, and we are exploring several possibilities with colleagues at the University of New Mexico.

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